

Two decades of vehicle-to-grid research show widely divergent profitability estimates

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ABSTRACT

The global electric vehicle fleet already stores more energy than all dedicated grid-scale batteries combined, yet this capacity remains largely untapped. Vehicle-to-grid could unlock it, but only if participation is profitable for vehicle owners. In this review, we harmonize 680 outcomes from 86 modeling studies to assess the profitability of vehicle-to-grid. We classify each article by the market segment generating vehicle-to-grid revenue, the model linking vehicles to that market, the point in the value chain the reported value describes, and the underlying modeling assumptions. Reported profitability estimates range from net losses to several thousand euros per vehicle, and most describe the value realized in the market rather than what a vehicle owner retains. The median study reports 201 EURper EV per year and 86% report a gain, yet study medians span more than an order of magnitude. Within individual studies, profitability increases with deployable flexibility and decreases with cycling costs. However, these relationships are obscured across studies because key design choices (including cost scope, market environment, and vehicle availability) vary simultaneously and cannot be disentangled. Genuine market heterogeneity and differences in modeling realism therefore co-vary and cannot be separated with the available evidence. At the same time, the conditions for profitability are improving, driven by falling battery prices, lower-than-assumed real-world degradation costs, and regulations beginning to recognize bidirectional storage. The question is no longer whether vehicle-to-grid can be profitable, but under which market and regulatory conditions it can scale.

1. Introduction

Power systems undergoing deep decarbonization depend on flexible resources that can absorb, shift, and re-inject variable renewable generation. At the same time, transport electrification is rapidly expanding the stock of controllable loads and mobile storage. By 2023, the global electric vehicle (EV) fleet exceeded 40 million units [1], with continued policy support [2,3] and declining battery costs [4,5] pointing to further growth. The aggregate battery capacity of this fleet already exceeds that of all grid-scale battery storage combined by roughly a factor of ten [6]. Yet this mobile fleet is a double-edged development: the same vehicles that strain local grids when charging is unmanaged [7,8] can absorb renewable variability, smooth supply and demand mismatches, and defer costly grid reinforcement when charging is coordinated [9–11]. Whether this mobile storage potential can be unlocked therefore becomes a central question for the energy transition.

Among flexibility resources, EVs stand out for combining large aggregate storage potential with strong behavioral constraints. Through bidirectional charging and discharging, often referred to as vehicle-to-grid (V2G), vehicles can inject stored electricity back into the grid and earn revenue for providing storage capability to the power system [12]. Unlike stationary batteries, however, their availability for grid services depends on choices made by vehicle owners themselves: whether and when to plug in, how much energy to reserve for driving, and how long the vehicle remains connected [13,14]. Because EV batteries are acquired for mobility rather than for grid service provision, V2G flexibility only reaches the grid if owners find participation profitable enough to offset the inconvenience and additional battery wear involved [15]. Empirical user studies identify financial benefits as a central driver of V2G participation, while non-financial factors such as convenience, range concerns, and data privacy also shape willingness to engage [16–18].

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Because bidirectional charging is not yet a mass-market technology, field evidence on its economics remains scarce: existing pilots demonstrate technical feasibility but rarely provide reliable economic evidence [19–21]. Investment, market-design, and regulatory decisions that will shape V2G are nonetheless being made now, ahead of such evidence, making harmonized modeling studies the primary basis for decision-making. Existing literature reviews on V2G modeling address system-level studies that quantify the value of managed charging by scheduling the entire fleet as a single operator [12], while others map deployment barriers [22,23]. Reviews that directly target profitability are similarly limited: one meta-analysis [24] combines a regression on study characteristics with only a brief narrative review, while another broader compilation catalogs outcomes without using a common metric [25]. Alongside these reviews, a growing body of individual modeling studies continues to estimate V2G economics for specific settings – its system-level value [11,26], the returns to competing flexibility as renewables scale [27], and residential profits under real-world charging [28] – yet each reports a single design under its own metric. A fully harmonized, systematic comparison of revenues and costs that determine individual V2G participation is therefore still missing.

Our review provides this harmonized basis and extends previous meta-analyses. It is the first systematic review focused specifically on the market-based profitability of V2G participation, harmonized to a common per-vehicle metric – a gap that has so far remained unaddressed. In addition, it builds on a larger, more recent, and fully harmonized evidence base, comparing 680 outcomes from 86 studies across 17 countries, each converted to EUR per EV per year; this is roughly twice the number of observations and more than twice the number of studies covered by the profitability meta-analysis of Heilmann and Friedl [24]. We classify each study along three dimensions: the market segment in which V2G earns revenue, the market integration model that links EVs to that market, and the modeling assumptions adopted, including price formation, plug-in availability, cost scope, and scheduling method. These dimensions connect to established work on electricity-market design, EV-grid integration, dynamic retail pricing, and V2G actor roles [10,28–31]. This lets us identify which assumptions drive the divergence and test whether reported profits respond to technical parameters as economic reasoning predicts, rising with deployable flexibility and falling with costs.

Three questions guide the analysis. First, which electricity market segments, market integration models, and modeling approaches does the literature cover, and where are the gaps? Second, what revenues and profits does the literature report once outcomes are harmonized to a common metric? Third, to what extent can differences in reported V2G profitability across studies be explained by systematic factors, and under which conditions do more consistent economic patterns emerge? Answering these questions reveals the technical, market, and regulatory conditions that determine V2G profitability, and clarifies where future modeling and policy work should focus.

The remainder of this paper proceeds as follows: Section 2 describes the systematic review and harmonization procedures; Section 3 introduces the classification framework; Section 4 describes the modeling inputs and methods; Section 5 presents the harmonized outcomes and their decomposition; Section 6 discusses market and regulatory implications; and Section 7 concludes.

2. Methodology

In this study, we first identify relevant articles through a systematic review (Section 2.1). We then harmonize the reported outcomes using a common methodology to enable comparative analysis across studies (Section 2.2).

2.1. Systematic literature review

This review was conducted and reported following the PRISMA 2020 statement [32]. Scopus and Web of Science were searched in January 2024 and updated in July 2026, with no publication-date limit. The query combined four Boolean concept blocks, *vehicle-to-grid*, *electric vehicle*, *economic outcome*, and *electricity market*, applied to title, abstract, and keyword fields. Synonyms within each block were joined with OR and the blocks with AND: vehicle-to-grid (vehicle-to-grid, grid-to-vehicle, bidirectional charging, V2G, G2V, smart charging); electric vehicle (electric vehicle, battery electric vehicle, plug-in electric and plug-in hybrid vehicle, and the abbreviations EV, BEV, PEV, PHEV); economic outcome (profit, revenue, cost, cost-benefit, cost reduction, infrastructure cost, battery degradation cost); and electricity market (energy trading, price arbitrage, peak shaving, load leveling and control, primary, secondary, and tertiary frequency control, spot market, ancillary service). The database search was complemented by a curated institutional reference list and by backward and forward citation searching of the studies that passed full-text assessment.

A record was included if it was a primary modeling study reporting an original, market-based profitability outcome, a profit or revenue, for the electric-vehicle owner, aggregator, or fleet that could be harmonized to euros per vehicle per year, and was written in English or German. Records were screened first on title and abstract and then on full text. Where a record failed more than one criterion, a single exclusion reason was assigned following a pre-specified hierarchy, so that each excluded report is counted once; the nine reasons and their counts are shown in Supplementary Figure S5 of the Supplementary Material. Of 456 records identified, 86 studies met all criteria and form the harmonized database of 680 profitability cases analyzed below. All 86 studies are listed in Tables 1,2, including those not discussed individually in the text [33–52]. A per-record audit trail for all 456 records is openly available (see Data availability), so that the search and every screening decision can be reproduced.

2.2. Data harmonization

The reviewed literature reports economic outcomes in heterogeneous formats, including annual per-vehicle values, lifetime net present values, total fleet-level earnings, and per-kilowatt-hour margins. To enable comparison across studies, we harmonize all outcomes to a common metric of EUR per electric vehicle per year. We distinguish two outcome measures. Revenue denotes the electricity market earnings reported by the study before any further cost deductions. Profit denotes the net result after subtracting those cost components that the study explicitly accounts for. Neither measure identifies which participant retains the amount, which is a separate dimension of the classification (Section 3.2). The gap between the two measures varies because studies differ in whether and how they represent battery degradation, charging infrastructure, regulatory costs, and other cost components (Section 4.4).

Harmonization proceeds in three steps. First, all outcomes are normalized to annual per-vehicle values; where a study reports on another basis, the conversion is documented case by case in the published dataset. Second, each value is deflated from the study's price base year to 2025 price levels using the consumer price index of the country modeled [53]. Third, the deflated values are converted to euros at the 2025 annual average exchange rate [54]. The same two steps are applied to the monetary input parameters a study reports, such as battery price, degradation cost and charging equipment cost, so that every monetary quantity in this review, whether an outcome or an assumption, is expressed in EUR at 2025 price levels. The resulting factors, and a comparison with a single common deflator, are reported in Supplementary Material, Section S1.

Some studies report results for multiple configurations that vary by market segment, country, vehicle characteristics, or assumed electricity

prices. We treat each configuration as a separate scenario whenever it produces a distinct economic outcome along at least one of these dimensions. When configurations cannot be fully disentangled because variation extends beyond the classification scheme used here, or because results are reported only graphically, we record the reported minimum and maximum values instead. Applying this procedure yields 680 scenarios from 86 studies. Of these, 484 report profit outcomes and 288 report revenue outcomes; 69 studies report a profit, 15 report revenue only, and 2 are qualitative. Studies contribute between one and 84 scenarios. To avoid overweighting studies with many scenarios, the study is the unit of analysis, represented by the median across its scenarios (Supplementary Material, Section S2). Each outcome is further classified by its position in the value chain as market value, aggregator profit, or owner net, based on the price entering the economic calculation (Supplementary Material, Section S4).

The sample spans publication years 2000 to 2026 and covers 17 countries across Europe, North America, and the Asia-Pacific. The underlying database and the full processing workflow from raw study data to harmonized outcomes are openly available, making all coding decisions and transformation steps transparent and reproducible. To probe whether cross-country differences in price levels or incomes drive the results, each outcome is additionally expressed in purchasing-power-adjusted euros and as a share of local GDP per capita; these serve only as a robustness check (Supplementary Material, Section S1).

3. Market participation of V2G

To trace the sources of this divergence, we first classify how V2G participation is organized along two dimensions: the market segment in which revenue is generated (Section 3.1) and the market integration model through which EVs access that market (Section 3.2). Throughout this section, where we describe what most, many, or some studies do, the citations that follow are illustrative examples rather than an exhaustive list of every study to which the statement applies. Fig. 1 maps these two dimensions and their connecting revenue logic.

3.1. Market segments

Most of the world's electric vehicles operate in power systems that either trade electricity in liberalized markets or are currently introducing them [55]: Europe and North America have relied on competitive wholesale markets since the 1990s [56]; China has been rolling out provincial spot markets since the late 2010s [57,58]; and many other countries have adopted elements of the same reform model over the same period, though often only in part [59,60]. Whatever value V2G creates for the power system, an owner or aggregator is paid only once a market product, a tariff, or a contract converts that value into a settlement. We therefore classify the literature by segment, the revenue environment in which EV flexibility is monetized [56]. Four recurring segments emerge from the coded studies: wholesale spot markets, balancing markets, retail tariffs, and a residual category of other arrangements outside standardized platforms (see Fig. 1). In plain terms, wholesale and intraday markets trade the electricity itself at prices that change from hour to hour [29]; balancing markets pay providers for standing ready to stabilize grid frequency and for delivering when called upon [10,61]; and retail tariffs pass time-varying prices through to end users, increasingly in dynamic form [28].

The segments differ in revenue logic. In wholesale spot markets and retail tariffs, value arises from arbitrage, that is, from shifting charging and discharging to exploit price differences. In balancing markets, value arises from committing capacity to remain available, with additional revenue when the system operator calls upon it. This distinction carries through to the harmonized outcomes: the two logics impose systematically different cost burdens on the vehicle (Section 5). Other arrangements capture mechanisms outside these settings, including contracted peak reduction, congestion management, and imbalance

settlement. Of the 86 studies reviewed, 29 address wholesale spot markets, 60 balancing markets, 8 retail tariffs, and 7 other arrangements including imbalance settlement, the charges for deviating from scheduled volumes, with 21 studies covering more than one segment.

In wholesale spot markets, day-ahead price differences provide the baseline arbitrage opportunity [62–66]; intraday and real-time markets, traded closer to delivery, extend it through larger within-day price differences and finer time resolution [63,64,67,68]. Arbitrage is predominantly temporal, with EVs charging when prices are low and discharging when prices are high [66,69–71]; where wholesale prices differ by location, it can additionally capture those spatial differences [72]. Almost all of the 29 wholesale studies treat electricity prices as exogenous model inputs and assume that any profitable bid is accepted. In reality, however, large V2G volumes can shift market prices, and not every bid is necessarily accepted. Only two of the 29 wholesale studies explicitly relax these assumptions: one embeds V2G bids in explicit day-ahead market clearing [73], while another derives prices from a model of how power plants are dispatched [74]. Reported wholesale revenues are therefore upper-bound estimates: at scale, V2G's own participation, alongside that of competing flexibility options, would narrow the price differences it relies on [27].

In retail tariff studies, EVs arbitrage against end-user electricity prices rather than wholesale prices [71,75]. Because retail tariffs bundle energy costs with network charges, taxes, and levies, the attainable price difference depends on tariff design rather than wholesale volatility alone [75]. The literature covers both time-of-use tariffs with predefined price blocks [65,71] and dynamic tariffs indexed to wholesale conditions [71,76]. A further dimension is the structure of the network charges themselves: emerging power-based tariffs, which price the monthly peak rather than energy volume, reward the peak shaving that flexible and bidirectional charging can provide, so the attainable value depends on this design as well [77]. Legacy time-of-use structures with low overnight rates may misalign with solar-rich price profiles where midday prices are lowest [65]. A recent analysis of an operating dynamic-pricing program, published after our search window, supports this segment logic: simulated residential V2G pays off only where price spreads, charger access, and installation costs align [28]. Whether retail V2G can be profitable therefore depends on a regulatory question that remains unresolved in many jurisdictions: how bundled components are treated for electricity fed back to the grid (Section 4.4).

In balancing markets, V2G is evaluated as a provider of reserve capacity that absorbs sudden mismatches between power supply and demand, a balance required to keep grid frequency stable [56]. The fast response capability of EV power electronics [78,79], combined with long parking durations [80], is widely cited as making EVs well suited for such services [79,81]. Revenue arises through a two-stage process: the EV first commits capacity to remain available, and some or all of that capacity may then be activated by the system operator [82–84]. The resulting revenue depends on the specific product design, which varies widely across regions [85]. Products differ in activation speed, ranging from seconds [82,85,86] to minutes [87], and in remuneration structure, from capacity-only [86,88] or energy-only payments [78] to combined capacity-and-energy [84] or performance-based schemes that reward accurate signal tracking [89,90]. Balancing markets are thus not a single product category but a diverse set of national arrangements with distinct remuneration and activation characteristics.

As in wholesale markets, almost all of the 60 balancing-market studies assume that every bid is accepted at the prevailing price. Most studies likewise treat activation signals as exogenous, meaning the model determines how much capacity the EV commits, but not whether or how often it is actually called upon to deliver [83,91]. Together, these assumptions eliminate the two main uncertainties an EV operator would face in practice: whether bids are accepted and whether capacity is activated. Only one of the 60 balancing studies embeds participation in a broader market model where V2G supply can affect clearing

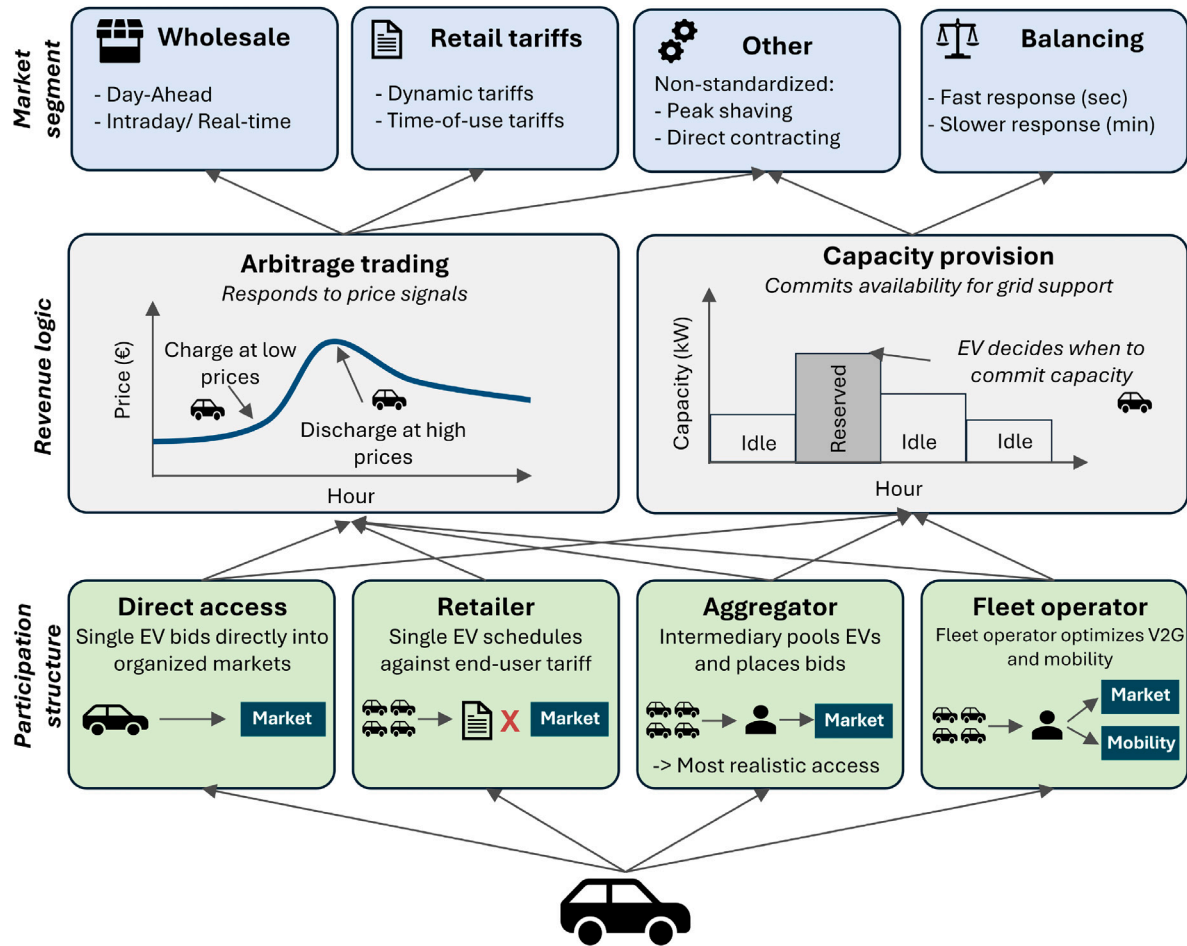


Fig. 1. Classification framework for V2G market participation. The top layer distinguishes four market segments; the middle layer shows the two underlying revenue logics (arbitrage trading and capacity provision); the bottom layer identifies four market integration models through which EVs access these markets.

outcomes [84]. Reported balancing revenues are therefore conditional on full bid acceptance and exogenous activation, and reflect the value of committed availability rather than demonstrated delivery.

A smaller body of work examines V2G in other arrangements outside standardized market platforms, including contracted peak reduction [92], residential load management [93], imbalance settlement [94], interruptible load programs [95], peak shaving [96], and carbon-linked remuneration [68]. Revenue here depends on bilateral contracts or administrative rules rather than competitive clearing, making reported values less transferable across settings [92,93,95]. These case-specific, non-standardized arrangements are therefore less suited than organized markets as a basis for large-scale V2G integration. The residual category also keeps the taxonomy extensible: if mechanisms such as local flexibility markets or capacity remuneration mature into standardized products, they enter the classification as additional segments with their own remuneration rules.

Many balancing-market studies involve a second market segment. In most cases, however, this segment serves only to settle the energy costs of reserve activation at wholesale spot [80,97,98] or retail prices [99–101] rather than as an independent source of revenue. A smaller number of studies jointly optimize energy and reserve offers across both segments, with each contributing to total revenue [67,84,102,103]. This distinction matters for interpreting reported revenues, as it determines whether value is generated from one segment or genuinely from multiple segments.

3.2. Market integration models

Market segments define where V2G revenue is settled. A second dimension concerns how participation is organized: which actors are involved, who bears scheduling and market access responsibilities, which costs the study includes, and which participant retains the reported value: the market as a whole, an intermediary, or the vehicle owner. We classify the literature along this dimension into four market integration models, distinguished by how these roles are allocated (see Fig. 1). This dimension matters because an individual vehicle can rarely meet market participation requirements such as minimum bid sizes on its own [14,104], so its flexibility typically reaches the market only once these roles are organized, most often through aggregation [30]. Of the 86 studies, 44 assume aggregator-mediated participation, 26 direct market access, 13 fleet operation, and 6 retailer-mediated participation, with 3 combining more than one structure. Arrangements now emerging in practice, such as energy communities or manufacturer-operated pools, recombine these same roles rather than adding new ones; the classification follows the allocation of roles, not the label of the actor.

Under direct market access, the EV interacts directly with the wholesale or balancing market, without an aggregator or other intermediary [13]. Some studies explicitly permit individual EV participation [90,97], while others acknowledge market constraints without actually modeling them [105]. In practice, however, individual vehicles cannot easily meet the technical and administrative requirements that

markets impose on participants. These include minimum bid sizes of 100 kW even for the smallest spot products and typically 1 MW in balancing markets, at least an order of magnitude above a single vehicle's charging power [14,104], formal certification that the resource can reliably deliver what it commits to [15,106], and bidirectional hardware with metering that meets regulatory standards [23,107]. Because most studies abstract from these requirements, reported direct-access revenues should be read as upper bounds, achievable only if these entry barriers do not actually constrain participation.

Under retailer-mediated participation, the EV charges and discharges in response to an end-user tariff rather than participating directly in a wholesale or balancing market [71,76,108]. Market access is mediated by the retailer who designs the tariff. The vehicle owner faces no prequalification, minimum bid sizes, or real-time communication requirements. Because an end-user tariff already embeds network charges, levies and the retailer's margin, value earned against it is what the owner retains. However, how the tariff itself is set is typically not modeled. Some studies adopt existing retail products [71,108], construct tariffs from wholesale prices plus network charges [76], or use simplified price profiles without specifying how the tariff is composed [109]. In all variants, the retailer's role in buying electricity wholesale and managing the imbalances created by V2G feed-in is not modeled [106]. Reported profitability is therefore sensitive not only to tariff design but also to how procurement risk is shared between retailer and EV owner, which most studies leave implicit.

Under aggregator-mediated participation, a third-party aggregator pools the flexibility of many individual EVs, combining their small capacities into a single portfolio large enough to meet market requirements [74,94,110]. This aggregator-mediated arrangement has long framed V2G implementation, with the aggregator serving as the interface between vehicles, system operators, and markets [30]. The aggregator then selects market segments [67,83,102], forms bids [68,111], and schedules charging and discharging under technical and mobility constraints [69,110]. This structure is closest to prevailing market rules, where minimum bid sizes effectively require pooling [104]. While aggregation resolves the market access barriers identified under direct participation, it introduces coordination costs and requires keeping a capacity buffer in case some EVs fail to deliver, both of which can reduce per-vehicle revenues [13]. However, even in studies that model aggregator-mediated participation, key market access requirements are often handled in stylized form or omitted entirely. Pooling is often treated implicitly, with spot market studies assuming portfolios large enough to meet bid thresholds [63,106], while only some balancing-market studies represent minimum bid sizes as explicit constraints [79,80]. Large-scale aggregation requires access to time-resolved data on vehicle availability and state of charge, yet privacy constraints may limit what information EV owners are willing to share [112]. Prequalification and regulatory cost components such as taxes and levies are rarely modeled [13,63,94,113].

Beyond this market-facing interface, the aggregator must also manage its relationship with vehicle owners whose participation must be incentivized. Most model the market side in detail but leave this second interface unspecified [69,114]: 17 of the 34 aggregator-mediated studies reporting a profit distinguish the aggregator's account from the owner's. Among those that do, the assumed arrangements vary widely. Some assume that the aggregator buys and sells energy from the vehicle at prevailing retail prices [82,89,115]. Others introduce explicit contracts that compensate owners for battery wear or constrained vehicle use [80,83,115]. A third group treats V2G as part of a bundled charging service in which flexibility provision is not separately remunerated [84]. Reported revenues under aggregator-mediated participation therefore reflect different levels of the value chain depending on which interface the study models, ranging from gross portfolio revenues before aggregation costs to net value received by the vehicle owner. Studies frequently do not state which of these a reported figure describes, so the position in the value chain is assigned

from the price entering the economic calculation rather than from the terminology used.

A subset of studies embeds V2G in the operation of vehicle fleets where mobility requirements take priority, including car-sharing services [62,116] and commercial or public-sector fleets [82,117,118]. These studies typically treat the fleet operator as both fleet manager and market participant without introducing a separate aggregator [62,113,116], implicitly assuming that the fleet operator meets all market participation requirements identified under direct access. V2G revenues are evaluated either as additional fleet income [62,116] or as a mechanism to reduce customer fares [113], with available flexibility constrained to residual idle capacity outside operational commitments. Reported revenues under this structure therefore reflect the electricity market value of residual idle capacity rather than full-scale V2G operation.

Across both market segments and market integration models, the reviewed studies share a common feature: they evaluate V2G under participation conditions more permissive than current markets allow. In wholesale and retail settings, studies typically assume that prices are not affected by V2G participation and that any profitable trade is accepted. In balancing markets, committed capacity is usually treated as both accepted and called upon when needed. Across market integration models, market access requirements such as minimum bid sizes, prequalification, and contractual arrangements between aggregators and vehicle owners are frequently simplified or omitted. These simplifications have two important implications. First, studies are not directly comparable across market segments or market integration models, even when they consider similar vehicles and technical assumptions, because their reported values reflect different market contexts and participation assumptions. Second, market access is generally assumed to be more permissive than the current market and regulatory environment allows or is likely to allow in the near term. Market context, however, is only one source of variation. Even within the same segment and market integration model, studies differ in their assumptions on price formation, vehicle availability, cost scope, and scheduling. The following section examines how these modeling choices further shape reported outcomes.

4. Modeling inputs and methods

Beyond the market context classified in the previous section, reported profitability depends on the operating conditions each study assumes, including the price environment, plug-in availability, and cost scope. This section assesses whether these conditions are representative of real-world V2G participation. It first characterizes the operating conditions and then examines the scheduling and commitment methods that translate these conditions into modeled revenues. The underlying datasets of this review are publicly available at <https://doi.org/10.5281/zenodo.22043327>.

4.1. Price and tariff environment

Studies do not evaluate V2G under a common price environment. Instead, they draw on electricity prices or retail tariffs from different countries, market segments, and time periods. Most studies (70 of 86) use historical price series or retail tariffs from a specific market and year, while 16 construct synthetic price paths ('Price input' in Tables 1,2). The underlying data span more than two decades [92] and cover North American, European, and Asian markets, with some studies combining data from multiple market areas [113]. The historical price environments underlying most studies reflect power systems with low shares of variable renewable generation and negligible EV penetration, because most price data predate the large-scale deployment of both. As both dimensions evolve, price formation may change substantially [119], altering the price differences and volatility patterns on which V2G arbitrage depends. Reported profitability estimates based on historical prices should therefore be understood as reflecting past

Table 1

Overview of reviewed V2G economic studies, Part I: Balancing markets. Sorted by publication year.

Study			Segment		Modeling approach					Cost scope			Reported profit EUR/(EV-yr)		
Author	Year	Country	Markets	Multi-segment	Market participation	Decision method	Reserve activation	Mobility input	Price input	Battery degradation	Charging infrastructure	Regulatory costs	min	median	max
Kempton	2005	USA	●		EV-direct	Simple estimate	Constant fraction	Time window	Historical	•	•	○	2527	3128	3728
Tomic	2007	USA	●		3rd Party access	Simple estimate	Historical signals	Travel survey	Historical	•	•	○	13	380	830
Larsen	2008	Denmark	●		EV-direct	Simple estimate	Constant fraction	Plug-in hours	Historical	○	○	○	–		
Camus	2009	Portugal	●		3rd Party access	Simple estimate	Constant fraction	Time window	Historical	•	•	•	–66	–66	–66
Quinn	2010	USA	●		EV-direct	Rule-based	Constant fraction	Synthetic profile	Historical	•	•	•	543	1069	2284
Andersson	2010	GER, SWE	●		EV-direct	Simple estimate	Historical signals	Plug-in hours	Historical	•	○	○	–99	405	909
Rezania	2012	Austria	●		3rd Party access	Simple estimate	Stochastic	Travel survey	Synthetic	•	○	○	–127	101	413
Luo	2012	USA	●		EV-direct	Simple estimate	Constant fraction	Synthetic profile	Historical	•	•	○	507	507	507
Quinn	2012	USA	●		3rd Party access	Rule-based	Constant fraction	Synthetic profile	Historical	•	•	○	–		
De Los Rios	2012	USA	●		3rd Party access	Simple estimate	Historical signals	Time window	Historical	•	•	○	–		
Sortomme	2012	USA	●		3rd Party access	Optimization	Historical signals	Travel survey	Historical	•	○	○	191	551	755
Ma	2013	USA	●		3rd Party access	Rule-based	Historical signals	Synthetic profile	Synthetic	•	○	○	1211	1211	1211
Jargstorf	2013	Germany	●		3rd Party access	Rule-based	Historical signals	Travel survey	Historical	○	○	○	132	132	132
Pelzer	2014	Singapore	●		EV-direct	Rule-based	Constant fraction	Travel survey	Historical	•	○	•	6	170	334
Zeng	2015	USA	●		EV-direct	Simple estimate	Historical signals	Time window	Historical	•	•	○	509	1183	1905
Ciechanowicz	2015	Singapore	●		EV-direct	Optimization	Constant fraction	Travel survey	Historical	•	○	○	371	391	410
Bishop	2015	UK	●		3rd Party access	Rule-based	Constant fraction	Travel survey	Historical	•	○	○	–		
Li	2015	USA	●		3rd Party access	Optimization	Constant fraction	Time window	Historical	•	•	○	–394	154	594
Noori	2016	USA	●		EV-direct	Simple estimate	Stochastic	Plug-in hours	Synthetic	•	•	○	1336	2079	3118
Zhao	2016	USA	●		3rd Party access	Simple estimate	Stochastic	Time window	Synthetic	•	•	○	34	70	116
Yao	2016	USA	●		3rd Party access	Optimization	Stochastic	Synthetic profile	Historical	•	○	○	67	69	113
Codani	2016	France	●		3rd Party access	Rule-based	Historical signals	Synthetic profile	Historical	○	○	○	–		
Thingvad	2017	Denmark	●		EV-direct	Simple estimate	Historical signals	Time window	Historical	○	○	•	–		
David	2017	USA	●		EV-direct	Simple estimate	Constant fraction	Time window	Historical	•	•	○	–42	109	350
Broneske	2017	Germany	●		3rd Party access	Optimization	Historical signals	Travel survey	Historical	•	•	•	–100	–21	29
Peng	2017	USA	●		3rd Party access	Optimization	Historical signals	Travel survey	Historical	○	○	○	–		
Hoogvliet	2017	Netherlands	●		3rd Party access	Rule-based	Historical signals	Time window	Historical	○	○	○	–183	31	271
Yao	2018	USA	●		3rd Party access	Optimization	Historical signals	Telematics	Historical	○	○	○	9	14	19
DeForest	2018	USA	●		3rd Party access	Optimization	Constant fraction	Synthetic profile	Historical	○	○	•	–9	–9	–9
Noel	2019	USA	●		EV-direct	Simple estimate	–	Time window	Historical	○	•	○	–		
Clairand	2019	Ecuador	●		3rd Party access	Optimization	Constant fraction	Synthetic profile	Historical	•	•	○	114	114	114
Han	2019	USA	●		3rd Party access	Optimization	Stochastic	Synthetic profile	Historical	•	○	○	2	2	2
Latini	2019	Italy	●		3rd Party access	Simple estimate	Historical signals	Time window	Historical	○	○	•	–		
Arias	2020	Denmark	●		EV-direct	Optimization	Historical signals	Plug-in hours	Historical	○	○	•	1185	1224	1259
Canevese	2020	Italy	●		EV-direct	Optimization	Historical signals	Time window	Historical	•	○	○	84	201	317
Calero	2020	Denmark	●		EV-direct	Rule-based	Historical signals	Synthetic profile	Historical	•	○	•	1168	1222	1277
Liao	2021	USA	●		3rd Party access	Rule-based	Constant fraction	Synthetic profile	Synthetic	•	•	○	539	1428	2318
Figgner	2022	Germany	●		3rd Party access	Rule-based	–	Telematics	Historical	○	○	○	–		
Blatiak	2022	UK	●		3rd Party access	Optimization	Constant fraction	Synthetic profile	Synthetic	•	○	○	31	506	1232
Al-Obaidi	2022	Canada	●		3rd Party access	Optimization	–	Synthetic profile	Synthetic	○	○	○	1873	1873	1873
Mugbel	2024	USA	●		3rd Party access	Optimization	Historical signals	Telematics	Historical	•	•	○	387	499	801
Owens	2024	USA	●		3rd Party access	Optimization	Stochastic	Telematics	Historical	•	○	•	–		
Owens	2025	USA	●		3rd Party access	Optimization	Stochastic	Telematics	Historical	•	•	○	37	81	136
Anggraini	2026	Sweden	●		3rd Party access	Optimization	Historical signals	Travel survey	Historical	•	○	○	–1,632	–1,349	382

Market segments: ● BM (balancing) ● DA (day-ahead) ● ID (intraday) ● RET (retail) ● OTH (other).

Multi-segment (*): study covers multiple segments simultaneously.

Decision method: *Optimization* (LP/MILP/MPC/DP, exact or heuristic solvers); *Rule-based* (charging, discharging, or capacity-commitment decisions via conditional logic, no objective function); *Simple estimate* (typical-parameter calculation, no temporal dispatch).Reserve activation (BM only): *Constant fraction* (constant share of bid is activated); *Historical signals* (real signals from past markets replayed); *Stochastic* (random activation events).

Cost scope: • included in profit; ○ not included.

Reported profit: Empty profit cells = value not reported.

Table 2

Overview of reviewed V2G economic studies, Part II: Multi-market, wholesale, retail, and other segments. Sorted by publication year within each group.

Study			Segment		Modeling approach					Cost scope			Reported profit EUR/(EV-yr)		
Author	Year	Country	Markets	Multi-segment	Market participation	Decision method	Reserve activation	Mobility input	Price input	Battery degradation	Charging infrastructure	Regulatory costs	min	median	max
Multi-market ($n = 18$)															
White	2011	USA	● ● ● *	*	EV-direct	Simple estimate	Constant fraction	Travel survey	Historical	• • ○			−369	698	5901
Shafie-khah	2012	Spain	● ● ● *	*	3rd Party access	Optimization	Stochastic	Synthetic profile	Synthetic	• • •			1778	1778	1778
Hu	2013	Denmark	● ● ● *	*	3rd Party access	Optimization	Historical signals	Travel survey	Synthetic	○ ○ ○			—		
Agarwal	2014	Singapore	● ● ● *	*	3rd Party access	Simple estimate	Constant fraction	Travel survey	Historical	○ ○ ○			1436	1436	1436
Shafie-khah	2016	Spain	● ● ● *	*	3rd Party access	Optimization	Stochastic	Travel survey	Synthetic	• • ○			148	148	148
Freeman	2017	USA	● ● ● *	*	EV-direct	Rule-based	—	Time window	Historical	• ○ ○			125	226	297
Alipour	2017	Canada	● ● ● *	*	3rd Party access	Optimization	Stochastic	Synthetic profile	Synthetic	• ○ ○			286	286	286
Gough	2017	UK	● ● ● *	*	3rd Party access	Simple estimate	Stochastic	Synthetic profile	Historical	• • ○			−271	1760	3791
Faddel	2018	USA	● ● ● *	*	3rd Party access	Optimization	Stochastic	Synthetic profile	Synthetic	• ○ ○			12	12	13
Thingvad	2019	Denmark	● ● ● *	*	3rd Party access	Optimization	Stochastic	Time window	Historical	• ○ •			1063	1176	1289
Wang	2020	USA	● ● ● *	*	3rd Party access	Optimization	—	Synthetic profile	Historical	• ○ ○			—		
Kocer	2021	TUR, USA	● ● ● *	*	EV-direct	Optimization	—	Time window	Historical	○ ○ ○			2232	2258	4437
Malya	2021	Germany	● ● ● *	*	EV-direct	Optimization	—	Time window	Historical	• ○ ○			51	465	856
Zheng	2022	USA	● ● ● *	*	3rd Party access	Optimization	—	Travel survey	Historical	• ○ ○			−172	−73	22
Tepe	2022	Germany	● ● ● *	*	3rd Party access	Optimization	—	Telematics	Historical	• ○ ○			−200	−151	137
El-Hendawi	2022	Canada	● ● ● *	*	3rd Party access	Optimization	Historical signals	Synthetic profile	Historical	• ○ ○			380	380	380
Gao	2023	USA	● ● ● *	*	3rd Party access	Optimization	Historical signals	Synthetic profile	Historical	○ ○ ○			−275	−194	−114
Metz	2024	USA	● ● ● *	*	3rd Party access	Simple estimate	Constant fraction	Synthetic profile	Historical	○ ○ ○			—		
Day-ahead/Intraday ($n = 12$)															
Loisel	2014	Germany	●		3rd Party access	Optimization	—	Travel survey	Synthetic	• ○ ○			−1	3	8
Pelzer	2016	CAN, SGP, USA	●		EV-direct	Optimization	—	Travel survey	Historical	• ○ ○			23	116	725
Kahlen	2018	Denmark	●		3rd Party access	Rule-based	—	Telematics	Historical	• ○ ○			179	179	179
Meisel	2020	Germany	●		3rd Party access	Optimization	—	Synthetic profile	Historical	○ • •			—		
Kern	2020	Germany	● ●	*	3rd Party access	Optimization	—	Travel survey	Historical	○ ○ •			—		
Caggiani	2021	ITA, NED	●		3rd Party access	Optimization	—	Synthetic profile	Historical	○ ○ ○			203	263	324
Fehrle	2021	Germany	●		3rd Party access	Optimization	—	Time window	Synthetic	○ ○ •			—		
Teske	2021	Germany	●		EV-direct	Optimization	—	Time window	Historical	○ ○ •			26	48	106
Wang	2021	UK	● ●		3rd Party access	Optimization	—	Synthetic profile	Historical	• • ○			554	554	554
Prencipe	2022	Netherlands	●		3rd Party access	Optimization	—	Travel survey	Historical	○ ○ ○			137	234	513
Crozier	2022	USA	●		EV-direct	Optimization	—	Plug-in hours	Historical	○ ○ •			133	133	133
Vollmuth	2024	Germany	● ●	*	EV-direct	Optimization	—	Synthetic profile	Historical	• • •			−209	−88	1830
Retail ($n = 6$)															
Peterson	2010	USA	●		Retail-mediated	Rule-based	—	Synthetic profile	Historical	• ○ •			21	21	21
Shang	2016	USA	●		Retail-mediated	Optimization	—	Synthetic profile	Historical	• ○ ○			−88	−24	1
Dogan	2018	USA	●		3rd Party access	Optimization	—	Synthetic profile	Historical	• ○ ○			95	95	95
Rodriguez	2020	USA	●		Retail-mediated	Simple estimate	—	Plug-in hours	Synthetic	• • ○			224	224	224
Steffen	2020	UK	●		Retail-mediated	Simple estimate	—	Plug-in hours	Historical	• ○ •			−32	−32	−32
Randleman	2021	USA	●		3rd Party access	Simple estimate	—	Travel survey	Synthetic	• ○ •			−0	28	1856
Other ($n = 6$)															
Kempton	2000	Japan	●		3rd Party access	Simple estimate	—	Travel survey	Historical	• • •			−24	61	143
Kempton	2001	USA	●		EV-direct	Simple estimate	—	Plug-in hours	Historical	• • ○			66	2773	13,679
Druitt	2012	UK	●		EV-direct	Rule-based	Historical signals	Synthetic profile	Historical	• ○ ○			126	126	126
Almehizia	2018	USA	●		EV-direct	Optimization	—	Time window	Historical	• • •			45	214	384
Tayarani	2019	Canada	●		3rd Party access	Optimization	—	Travel survey	Historical	• • ○			2536	2536	2536
Syed	2020	Belgium	●		3rd Party access	Optimization	—	Time window	Historical	○ ○ ○			83	1063	1649

Market segments: ● BM (balancing) ● DA (day-ahead) ● ID (intraday) ● RET (retail) ● OTH (other).

Multi-segment (*): study covers multiple segments simultaneously.

Decision method: *Optimization* (LP/MILP/MPC/DP, exact or heuristic solvers); *Rule-based* (charging, discharging, or capacity-commitment decisions via conditional logic, no objective function); *Simple estimate* (typical-parameter calculation, no temporal dispatch).Reserve activation (BM only): *Constant fraction* (constant share of bid is activated); *Historical signals* (real signals from past markets replayed); *Stochastic* (random activation events).

Cost scope: • included in profit; ○ not included.

Reported profit: Empty profit cells = value not reported.

Table 3

Input parameter ranges across the reviewed studies. *N* denotes the number of studies reporting the parameter; each study is represented by the median across its scenarios, consistent with the study-level analysis used throughout. Ranges therefore describe typical assumptions rather than individual sensitivity extremes.

Parameter	<i>N</i>	Min	Q25	Mdn	Q75	Max
Mobility & availability						
Driving distance (km/day)	44	11.0	32.0	41.8	52.2	258.8
Parking time (h/day)	60	0.4	13.0	16.5	21.0	23.0
Fleet size (10 ³ veh.)	51	0.00	0.05	1.0	10.0	471.9
Vehicle & battery						
Battery capacity (kWh)	81	4.0	22.0	29.0	50.0	135.0
SOC minimum (%)	38	0.0	0.2	12.5	20.0	50.0
Charge/discharge power (kW)	77	1.2	6.6	10.0	16.5	100.0
Round-trip efficiency (%)	64	73.0	81.0	85.0	90.0	100.0
Cost components (EUR 2025)						
Battery price (/kWh)	49	0.0	210.7	331.2	446.4	1339.0
Degradation cost (/kWh)	41	0.00	0.05	0.10	0.12	1.70
Equipment cost (/veh.)	26	0.0	589.1	780.5	1456.5	4444.5

system conditions rather than the future market environments in which large-scale V2G deployment would actually occur.

Studies also differ in the temporal resolution of the price data they employ. Most use time-resolved price series that allow interval-level scheduling decisions [64,67,73], while a smaller subset relies on aggregated indicators such as average price differences [62,116], limiting the analysis to stylized revenue estimates rather than explicit dispatch. In balancing market studies, the price environment additionally includes reserve capacity prices and assumptions about activation, ranging from historical dispatch records to assumed fixed activation ratios (Section 4.5). As with wholesale prices, most reserve price data reflect historical conditions and may overstate future revenues, since the reserve market increasingly attracts flexibility from stationary batteries, demand response, and other distributed assets, intensifying competition for reserve provision. The choice of price environment alone can therefore generate substantial variation in reported profitability.

4.2. Availability, plug-in behavior, and mobility representation

V2G revenues depend on the vehicle being connected to the grid when market opportunities arise. The reviewed studies represent this availability in markedly different ways, spanning a spectrum from highly stylized to empirically grounded approaches ('Mobility input' in Tables 1,2). At the stylized end, studies use fixed daily connection hours [120] or deterministic availability windows [94,108]. In the middle, they generate trip profiles from statistical distributions [71,83]. At the empirical end, they draw on national travel surveys [79,116,121,122] or measured vehicle telematics [73,123]. The latter are typically limited to small and non-representative fleet samples. These choices affect both the amount and the timing of flexibility available for market participation.

Across the reviewed literature, grid-connection assumptions are often more optimistic than real-world evidence suggests. Reported parking durations range from 0.4 to 23 h per day, with a median of 17 h (Table 3), and most studies treat parking time as equivalent to plug-in time [13,122] ('Reserve activation' in Tables 1,2), thereby assuming that every parked vehicle is dispatchable. Only a small subset models plug-in decisions stochastically [67,68]. Daily driving distances range from 11 to 259 km (median 42 km, Table 3), while charging is assumed to occur primarily at home [112,122] and at the workplace [94,112]. Because mobility remains the primary function of the vehicle, driving reduces both the time available for grid connection and the share of battery capacity that can be committed to grid services.

In practice, dispatchable V2G flexibility requires at least three separate conditions, which most studies collapse into a single availability assumption. First, bidirectional charging infrastructure must be installed at the parking location, a requirement examined in Section 4.4. Second, the vehicle owner must actually plug in the vehicle when parked. In a representative survey of EV owners without access to

a V2G program, reported plug-in probabilities peak at only about 25% [124]. Even in a structured pilot with bidirectional infrastructure and self-selected participants, average plug-in availability reaches only about 61% [124]. This figure likely represents an upper bound, given the short trial duration and highly motivated participant pool. Third, even users who regularly plug in may still decline participation because of concerns about battery degradation, range anxiety, or loss of control [23]. By implicitly assuming that infrastructure is available, that parked vehicles are plugged in, and that connected users participate, many studies compound optimistic assumptions, likely overestimating the flexibility that would be dispatchable under real-world conditions.

4.3. Technical vehicle parameters

All studies characterize EVs through battery capacity, charging and discharging power, and round-trip efficiency. The assumed parameter ranges vary widely across the reviewed literature (Table 3). Battery capacities range from under 20 kWh in early studies [92] to about 100 kWh in recent passenger-EV analyses [72,94] and up to 135 kWh in a commercial-fleet study [125]. Charging power assumptions cluster around 10 kW, although higher ratings appear in depot or fast-charging applications [63,67]. Round-trip efficiency assumptions lie between 73% and 100% (median 85%), with a single sensitivity scenario as low as 10% [78]. Much of this variation follows technological evolution over two decades rather than different assumptions about comparable vehicles. Unlike the price, availability, and cost assumptions examined in the surrounding sections, technical vehicle parameters are largely determined by the commercially available vehicle model under study and leave comparatively little room for methodological discretion.

4.4. Cost scope

Whether a study reports net benefits depends not only on estimated revenues but also on the scope of costs considered. With battery degradation accounted for in 60 of 86 studies, bidirectional charging infrastructure in 30, and regulatory cost components in only 24, the cost scope (Tables 1,2) is one of the most heterogeneous dimensions across the reviewed literature.

Battery degradation is usually approximated as a fixed cost per kilowatt-hour discharged [65,79,112,126], applied either ex post as a deduction from gross revenues [79,126] or directly within the scheduling objective [68,115]. In the latter case, degradation sets a minimum price difference below which dispatch is not profitable. Assumed values range from near zero to 1.70 €/kWh, with a median of 0.10 €/kWh (Table 3). Reported capacity losses of 5 to 30% over the first 1500 full charge-discharge cycles [127,128], combined with current battery pack prices of approximately 96 €/kWh [5], suggest degradation costs of approximately 0.01 €/kWh. Although this first-order estimate omits the nonlinear dependence of aging on depth of discharge, C-rate,

and temperature [129], it suggests that the literature median exceeds empirically grounded values roughly tenfold. Typical V2G operation, at low power and with actively managed charge levels, is associated with slower aging than throughput-based penalties assume [129], reinforcing this conclusion.

Infrastructure costs are included in only 30 of 86 studies, and several of these exclude charging equipment costs explicitly [62,72,116,130]. Among those that include them, definitions range from the charger unit alone [131] to broader scopes covering installation or grid connection costs [132] (Table 3). The median assumed value is 780 € per vehicle, well below the price of the lowest-cost bidirectional charger available as of 2025, at just over 2000 € [133]. A recent German techno-economic study modeling a DC bidirectional charger likewise places the incremental hardware cost far above the literature median, at roughly 4350 € per vehicle today (of which the charger unit alone accounts for over 80%), and projects a decline to about 1675 € by 2030 as bidirectional chargers scale up [134]. Beyond charger prices, bidirectional charging requires certified smart metering, communication protocols, and backend infrastructure [22], components that most profitability studies do not account for. Infrastructure costs in the reviewed literature are therefore likely to understate the actual cost of V2G participation, both in the level of assumed charger costs and in the scope of system components considered.

Regulatory cost components, included in 24 of 86 studies, are modeled least often and least consistently. This low coverage is consequential because the effective price an EV faces is determined not only by the energy market but also by network charges, taxes, and levies. In many jurisdictions, these non-energy components constitute the majority of the end-user electricity price, meaning that regulatory treatment can have a larger effect on V2G profitability than wholesale price dynamics [75]; where electricity fed back to the grid is not credited against what was drawn, this alone can roughly halve frequency-regulation revenue and turn behind-the-meter arbitrage negative [135]. Moreover, existing regulatory frameworks in most jurisdictions do not recognize bidirectional storage as a distinct category between consumption and generation [136]. When electricity is withdrawn from and later re-injected into the grid, levies or network fees may therefore apply twice, yet such costs are rarely quantified [75]. Among studies that do include regulatory costs, approaches vary widely. Some apply a flat surcharge to electricity prices without separating taxes and levies [63,64,71], while others include selected fiscal items such as value-added tax [97] or carbon-related charges [65,68,137]. Only one study represents asymmetric fiscal treatment, where levies apply to negative but not positive reserve provision [80]. Several EU member states impose restrictive requirements for participation in balancing and congestion management services [138], and Maryland became the first U.S. state to establish V2G-specific regulations only in 2024 [139]. Because regulatory frameworks vary substantially across jurisdictions, profitability estimates that omit these costs should be interpreted with the specific regulatory context in mind.

4.5. Scheduling and commitment methods

Even where the operating conditions examined above are held constant, the method used to translate these conditions into reported revenues introduces a further systematic source of variation. The dominant approach is optimization under perfect foresight, which yields revenues that constitute an upper bound on what can be achieved in practice. A recent study makes this explicit, framing its perfect-foresight results as an upper bound that forecast errors and uncertain plug-in times would erode in operation [77]. However, the range of alternative approaches is wide ('Decision method' in Tables 1,2).

In spot and retail settings, the central modeling task is to determine when and how much to charge or discharge. Optimization-based approaches formulate this as a mathematical program maximizing arbitrage profit or minimizing charging cost subject to state-of-charge

limits, round-trip efficiency losses, charger power ratings, and mobility-driven connection windows [68,116]. Most optimization studies assume perfect foresight of prices and driving patterns; only a few relax this through stochastic [84], robust [140], or fuzzy formulations [89]. Where non-linearities arise, studies employ heuristic solvers [80,109,123]. A smaller subset embeds V2G into unit-commitment models in which prices emerge endogenously [74], partially addressing the system consistency concern identified in Section 4.1. Rule-based approaches derive decisions through conditional logic without formulating an objective function, for instance discharging whenever the price exceeds a predefined threshold [65,108], with thresholds derived adaptively from price history [76] or set to cover degradation costs [70,130]. Aggregate estimation methods derive V2G value from summary parameters without time-resolved scheduling, multiplying average price differences by available capacity [108] or assuming fixed schedules [92,120,141]. These methods are useful for long-run approximation but capture less of the price variability and operational constraints that determine realizable revenues.

In balancing markets, the modeling problem has two distinct stages: the model first determines how much reserve capacity the vehicle or fleet commits, and then represents whether and how that committed capacity is activated. For commitment, optimization-based studies formulate reserve bids as decision variables, maximizing capacity payments alone [142] or additionally accounting for expected activation revenues [82,83,101], recharging costs [80,82], or battery degradation [83,89,105]. Several studies jointly optimize reserve commitment and energy-market scheduling [88,89,114]. Rule-based approaches aggregate vehicle availability and state-of-charge headroom into deliverable capacity per interval [79,132], while aggregate estimation approaches treat committed capacity as an input parameter [81,87,95,141,143].

How activation is represented ('Reserve activation' in Tables 1,2) has direct consequences for reported revenues. Several studies assume a fixed dispatch fraction, with ratios ranging from a few percent [101] to full, continuous dispatch [82,105]. Others replay recorded dispatch signals [80,85,111], and a smaller group models dispatch as uncertain using scenario trees [83,88] or Monte Carlo sampling [81]. Some studies omit activation entirely, so that reported revenues reflect capacity payments only [95,141]. Whether activation feeds back into the commitment decision further differentiates studies [83,88,142]. Balancing-market results are therefore conditional on how activation is modeled, even when nominally similar reserve products are considered.

Across the dimensions examined in this section, a consistent pattern emerges: the assumptions under which the literature evaluates V2G profitability tend to be more favorable than real-world conditions. Price environments are drawn from systems with negligible EV penetration. Vehicle availability is assumed more generously than empirical plug-in data support. Cost scope is incomplete, with infrastructure and regulatory costs omitted more often than not. Moreover, the dominant scheduling method produces revenues that represent an upper bound on what real-world operators could extract. Whether these assumptions systematically shape reported outcomes can only be tested for dimensions that are reported consistently and admit a defensible ordering. We therefore examine mobility representation, balancing-market activation, and cost completeness quantitatively, while treating less consistently reported or non-ordinal dimensions as contextual sources of heterogeneity.

Together with the permissive market access assumptions identified in Section 3, these differences imply that studies examining otherwise similar V2G applications may still report substantially different economic outcomes. The following section therefore harmonizes the reported values to a common metric and examines whether the dimensions identified above help explain the observed variation.

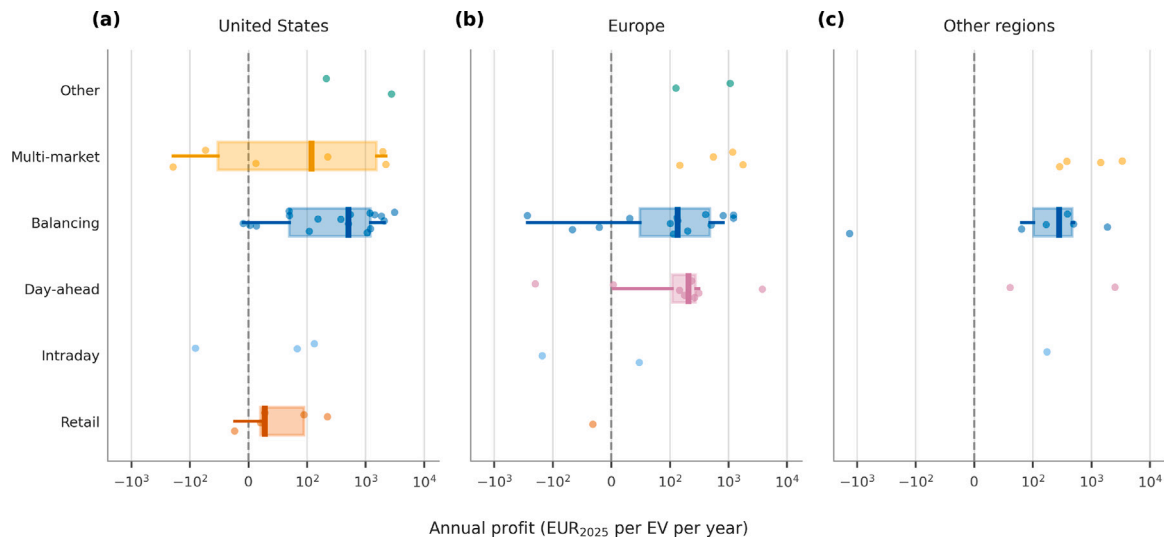


Fig. 2. Reported annual V2G profits by market segment and region at the study level ($n = 69$ studies). Each point is one study's median within that region and segment, so studies contributing many sensitivity scenarios do not dominate. Box plots show the median and interquartile range for groups with $n \geq 5$. The x axis uses a symmetric logarithmic scale. Direct comparison of absolute values across segments and regions is constrained by differences in modeling choices and market environment, but the relative patterns are informative.

5. Economic viability of vehicle-to-grid

Reported V2G outcomes range from net losses to substantial annual earnings per vehicle (see Fig. 2). Given the equally large variation in market settings and modeling assumptions documented in the preceding sections, a central question is whether this spread reflects actual disagreement about V2G economics or whether it results from differences in what each study evaluates. To address this question, we have made the outcomes comparable across studies, markets, and time periods (see Section 2.2).

Across the 69 studies that report a profit, the median reported profit is 201 EUR per EV per year (interquartile range 48–698; 95% confidence interval 116–380, cluster bootstrap over studies). Most of these studies report the value realized in the market rather than what an owner retains, a distinction taken up below. Study medians range from –1,349 to 3128 EUR (10 of 69 negative; leave-one-study-out median 190–208 EUR). Revenues have a median of 694 EUR per EV per year ($n = 49$ studies). At the scenario level, profits span –1,632 to 13,679 EUR (median 382; $n = 484$), the wider dispersion reflecting the sensitivity cases individual studies contribute. The literature thus shows broader agreement on the direction of V2G value than on its magnitude: 86% of studies report a positive median outcome, yet the study medians span three orders of magnitude.

How much revenue remains as profit depends on the costs a study deducts, one of the most heterogeneous dimensions across the reviewed studies. As the comparisons below show, its apparent effect is entangled with market segment and region rather than separable as the single dominant driver. Where a study reports both revenue and profit for the same scenario, the total deduction can be read directly, without any comparison across studies: the median study deducts 73% of its revenue (148 scenarios from 33 studies). This measures everything a study subtracts, principally the cost of the energy bought before it is sold. Comparisons across studies are far less stable: at the scenario level, cases including all three tracked components report a near-zero median against 878 EUR for those omitting all three, but at the study level the contrast largely disappears (138 vs. 234 EUR; $n = 6$ vs. 9 studies; bootstrap interval –1,129 to +1189 EUR), so the apparent effect of cost scope is driven substantially by how many scenarios individual studies contribute.

However, this profit contrast cannot be attributed to cost scope alone, because the two groups also differ systematically in study design.

Scenarios omitting all costs are predominantly European studies in non-standard market segments such as contracted peak reduction or congestion management, while those including all three are concentrated in balancing markets and more evenly distributed across regions. Adding cost components does not consistently reduce profit, reinforcing this confounding: studies including two cost components report a higher median profit than those including only one (380 vs. 126 EUR; $n = 27$ studies each), although this difference is no more resolvable than the others. The direction is consistent with the concentration of that group in U.S. studies accessing high-revenue markets regardless of cost assumptions. The observed contrast is therefore consistent with joint variation of cost-modeling scope and market context rather than with a clean cost-profitability relationship.

In the available studies, market segments differ not only in the revenues they generate but also in the share of these revenues absorbed by costs (Fig. 2). Day-ahead and intraday markets show a higher median revenue than balancing markets (1405 vs. 679 EUR; $n = 4$ vs. 26 studies), but reported deductions amount to 90% of revenue in these arbitrage-based segments against 58% in balancing markets, so the resulting median profits are lower (133 vs. 201 EUR; $n = 9$ vs. 33 studies). Neither difference is resolvable at the study level. The mechanism is straightforward: arbitrage earns on a price difference, so the energy must be bought before it is sold and the purchase consumes most of the gross revenue, whereas balancing participation is remunerated for committed availability and involves less throughput, so a larger share survives as profit. V2G viability therefore depends not only on the level of market prices but also on the revenue mechanism: business models paid for capacity availability face lower cost barriers than those relying on repeated charging and discharging. Within balancing markets, reported values also differ by region (440 vs. 170 EUR; $n = 18$ U.S. vs. 15 other studies), consistent with differences in product design and prevailing price levels within the same segment, although the difference is not resolvable.

Studies that idealize driving and parking assumptions report higher profits than those built on empirical mobility data, though the difference is not resolvable at the study level. The empirical group, using travel surveys or measured telematics, reports a lower study-level median than studies assuming fixed or stylized schedules (140 vs. 226 EUR; $n = 22$ vs. 47 studies). At the scenario level the difference interval excludes zero, whereas at the study level it does not, so weighting by study removes an apparent effect that arises under scenario-level

weighting. The difference concerns mobility realism rather than plug-in behavior: almost all studies, empirical ones included, treat the vehicle as connected whenever parked, so the further drag of real plug-in decisions remains unmodeled.

The three dimensions discussed above, cost scope, market setting, and vehicle availability, are associated with systematic differences in reported outcomes, but do not fully explain the observed variation. Even studies that examine similar market segments within the same region and with broadly comparable cost scope can reach markedly different conclusions. Three U.S. balancing-market studies, for example, report median profits of 12, 154, and 550 EUR [89,99,115], consistent with differences in scheduling assumptions and other elements of study design. Across the full sample, no single study characteristic consistently separates high-profit from low-profit estimates (Fig. 3), and reported profits show no tendency to converge over time. Across two decades of growing methodological sophistication, the three-year rolling median of study-level values moves without direction, and the interquartile range around it does not narrow (Fig. 4a). The cost-modeling scope has improved over the same period (Fig. 4b), but this has not been accompanied by a reduction in the overall spread of reported outcomes.

Given the persistent spread in reported outcomes, a natural question is whether individual technical parameters, such as battery price, charging power, or degradation cost, can at least partially explain the observed differences. Across studies, however, the expected relationships between these parameters and reported profitability are not recoverable (Fig. 3). Studies that assume higher battery prices do not systematically report lower profits, nor do studies with higher charging power systematically report higher profits, despite the clear economic expectation that both should matter. For degradation cost, the relationship across studies is even reversed: studies with higher degradation cost assumptions tend to report higher profits, which is consistent with their concentration in more lucrative market settings, particularly early U.S. frequency-regulation markets where capacity payments were exceptionally high. The reason these relationships are not visible across studies is that studies differ simultaneously in market segment, cost scope, availability assumptions, and other modeling choices. No single parameter effect can be disentangled from this web of co-varying study-design choices. A quantitative analysis of parameter associations across and within studies is provided in the Supplementary Material, Section S3.

This inconsistency across studies does not, however, imply that V2G profitability lacks any underlying economic structure. When technical parameters are varied within individual studies, holding market context, scheduling method, and cost scope fixed, reported profit moves in the economically expected direction for all ten technical parameters tested: in every case the within-study correlations point predominantly the way economic reasoning predicts. Most studies vary several parameters at once, so an individual correlation measures the response to a bundle rather than to its named parameter; directional agreement remains strongest where one to three retained parameters vary together and weakens substantially when four or more co-vary. Reported profit is negatively associated with battery price wherever it is varied in isolation. This directional regularity does not survive aggregation across studies: when study-level medians are compared, only two of the ten parameters retain the expected direction, the rest being obscured by the bundling of design choices (Supplementary Material, Section S3). Effect sizes vary widely even where the direction is stable: the increase in reported profit per additional kW of charging power ranges from 2 to 447 EUR ($n = 12$ studies). The within-study regularity therefore shows that the economic logic of V2G is present in the literature, while its disappearance across studies supports our central finding: market settings, cost definitions and modeling choices vary together across the literature, so no single technical-parameter effect generalizes across the heterogeneous evidence base.

We next examine whether two additional dimensions of comparability can explain the remaining differences in dispersion across national price levels and the economic perspective captured by the reported outcome. The results suggest that they do not: reported outcomes are robust to differences in purchasing power and local income. Re-expressing every case in purchasing-power-adjusted euros or as a share of local GDP per capita leaves the profit-or-loss sign unchanged and largely preserves the country ordering (Spearman $\rho = 0.98$ and 0.89 ; $n = 16$ country medians; Fig. 5a). The spread of reported profits is essentially the same under all three measures (Fig. 5b), and within any single country it remains far wider than the differences between country medians (Supplementary Figure S1). The dispersion in reported profitability is therefore not a by-product of comparing countries with different price levels or incomes.

Reported figures also differ in where along the value chain they sit, which we code for every case. Most studies leave it implicit: 49 model no split between market and owner, while 10 report an aggregator's margin and 10 an owner's net position. The corresponding medians are 214, 217, and 30 EUR per EV per year ($n = 49, 10$, and 10 studies), but no pairwise difference is resolvable and the groups differ in more than perspective: owner-level positions are reported mainly for retail-tariff arbitrage and market values mainly for balancing and spot participation. Within studies the effect is unambiguous. Where a single study reports several perspectives for identical scenarios, the aggregator's profit exceeds the owner's net position by about 2000 EUR per EV per year and the sign changes. Market-value figures should therefore not be interpreted as owner-realized returns and, where an explicit split is absent, are better understood as gross value before any intermediary margin or owner-compensation mechanism is modeled (Supplementary Material, Section S4).

Restricting the analysis to studies with a comparable cost scope does not lower the reported values. Among studies internalizing both battery degradation and charging infrastructure costs, the median is 499 EUR per EV per year ($n = 25$ studies), higher than across the corpus rather than lower (Supplementary Material, Section S4).

Every design dimension examined here is associated with differences in reported medians, yet none survives once the analysis moves to the study level and uncertainty is quantified: the bootstrap intervals above all include zero (Supplementary Material, Section S2).

Applying the realism criteria derived in Section S4.3 of the Supplementary Material leaves the result intact. Applied separately, each criterion leaves the median positive (97–439 EUR per EV per year), and meeting a criterion does not systematically lower the reported value: of the nine applicable criteria, three are associated with a higher median and six with a lower one (Supplementary Material, Section S4).

Taken together, the reviewed literature reports predominantly positive V2G profits, but under modeling assumptions that tend to favor positive outcomes. Incomplete cost scopes, availability assumptions that exceed empirically observed plug-in rates, differences in market setting, and the actor perspective underlying reported values all contribute to the spread in reported outcomes. However, their effects can be identified only within studies, not across them, because these factors tend to co-vary. Section 6 examines the implications of these findings for market design, business model viability, and future research priorities.

6. Discussion

The V2G profitability literature agrees that modeled V2G is usually profitable but not on how much. About 86% of studies report a positive median outcome, but across our 680 harmonized outcomes from 86 studies profits range from net losses to several thousand EUR, with no narrowing over two decades. This spread has two sources. Studies evaluate genuinely different use cases, set by market segment, the actor who captures value, and the regulatory treatment of bidirectional flows. They also differ in how realistically each pathway is modeled.

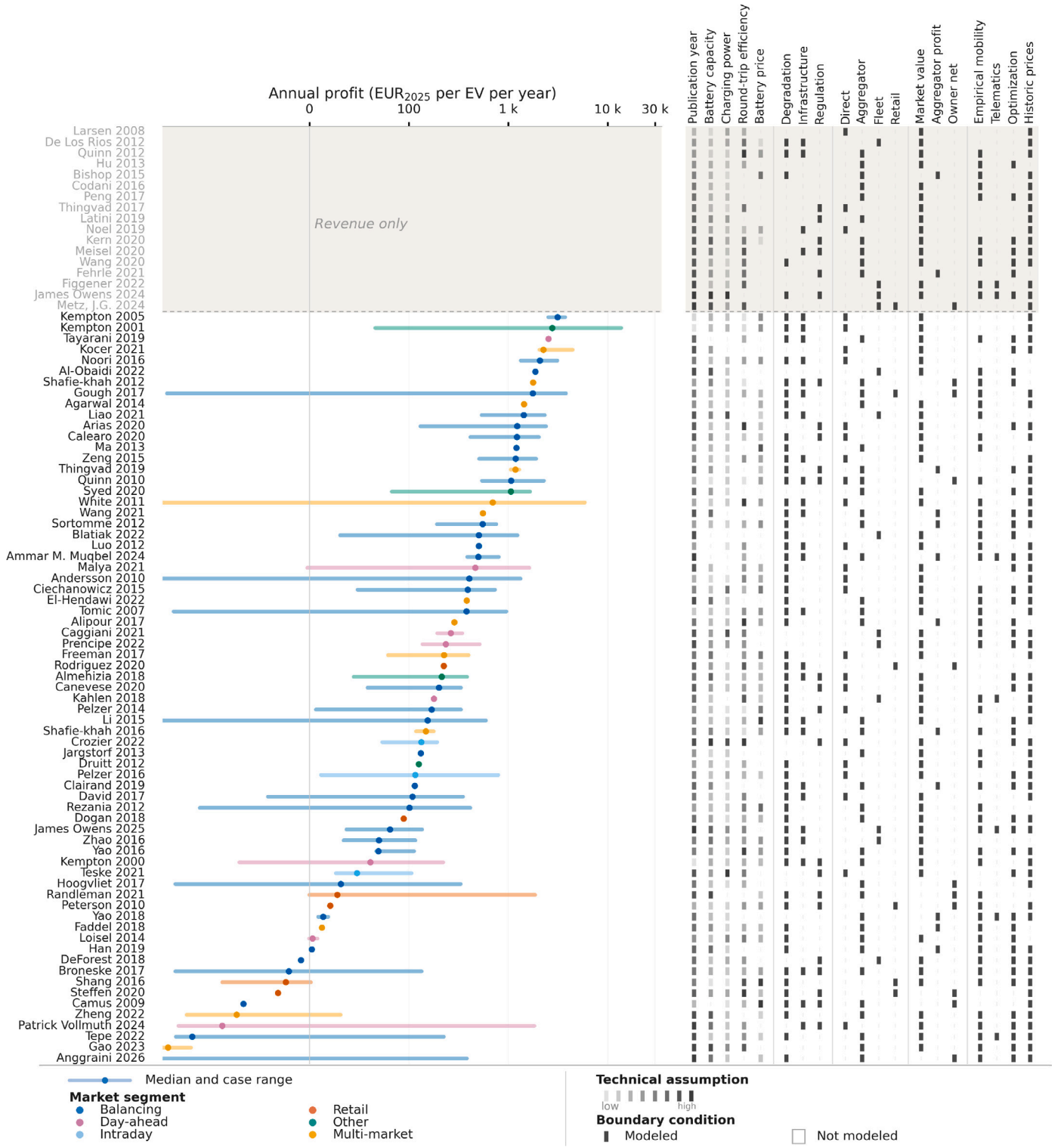


Fig. 3. Study-level overview of reported V2G profits and modeling characteristics ($n = 86$). Left: range of reported annual profits per study, ordered by study median. Right: study-level input and method characteristics, including the position in the value chain that the reported figure describes. For the five technical parameters, stroke opacity scales with the value a study assumes, normalized across the corpus; for the binary characteristics a dark stroke indicates the characteristic is present. Each study carries exactly one value-chain position, the modal position of its cases, so the three columns partition the studies.

Reported profits are therefore not estimates of a single V2G value but conditional values that combine a use case with a level of modeling realism. This is why an earlier meta-regression [24] on a smaller subset

does not replicate on our larger sample. In the following, we discuss the realism of the modeling assumptions (Section 6.1), the distinct characteristics of EV flexibility (Section 6.2), market segments and

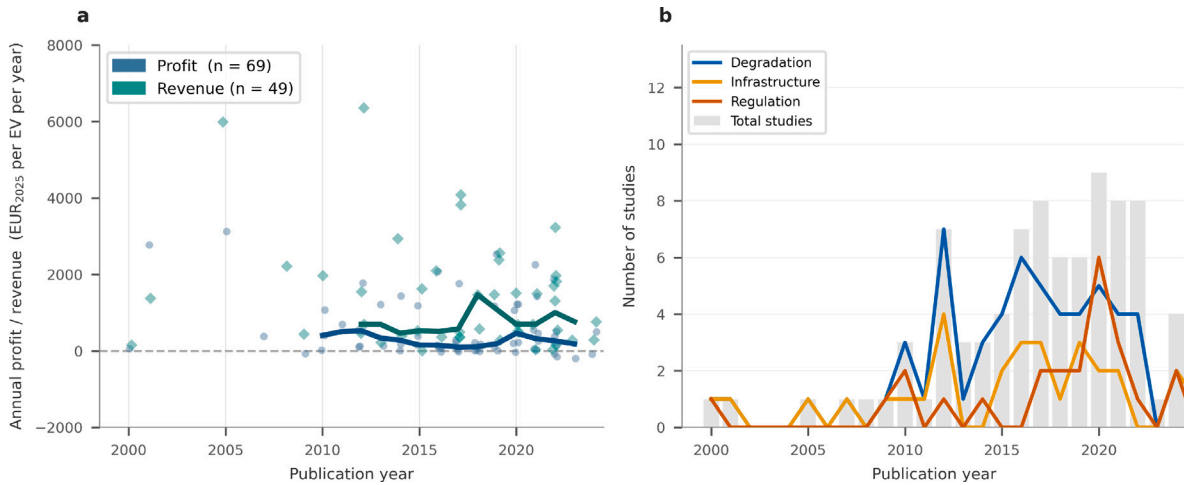


Fig. 4. Temporal evolution of reported V2G values and cost-modeling practices. **a**, Study-level revenue and profit by publication year, each study contributing the median of its scenarios, with three-year rolling medians. **b**, Number of studies per year and cost-modeling scope.

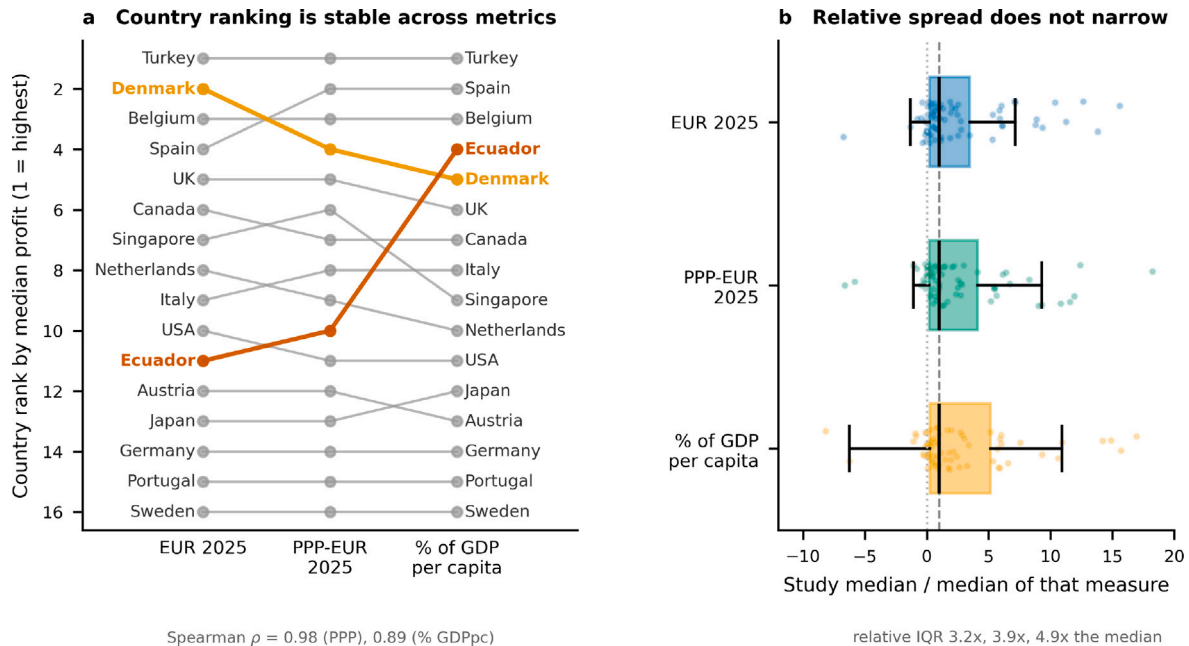


Fig. 5. Robustness of reported profitability to national price levels and incomes, at the study level. **a**, Country rank by median profit under the three measures (absolute EUR 2025, purchasing-power-adjusted PPP-EUR, and share of GDP per capita); the ordering is largely preserved (Spearman $\rho = 0.98$ for PPP-EUR and 0.89 for share of GDP per capita, across 16 country medians). Ecuador and Denmark are the only marked movers, Ecuador rising seven ranks under the income measure in the direction implied by its low GDP per capita and Denmark falling three. **b**, Distribution of reported annual profit under all three measures, each normalized to its own median so the differing units become comparable; the relative spread does not narrow but widens (interquartile width 3.2x, 3.9x and 4.9x the median), so adjusting for price level or income does not compress the dispersion.

fleet-scale absorption (Section 6.3), the implications of our findings (Section 6.4), and study limitations (Section 6.5).

6.1. Limited realism of modeling assumptions

Modeling effort has concentrated on the operational core of V2G and neglected the conditions that decide owner-level profit. The field has optimized dispatch more carefully than the conditions under which dispatch becomes commercially deployable: Charging and discharging are optimized in detail, battery degradation is costed in most studies, and battery capacity, charging power, and efficiency are always specified. The surrounding conditions are treated far less consistently, with bidirectional charging hardware costed in only 30 of 86 studies, regulatory costs in 24, and stochastic plug-in behavior in even fewer.

These rarely modeled dimensions are exactly those that drive real profitability. The requirements for a realistic model fall into three layers, the vehicle and its equipment, the operating decision that commits its capacity, and the market and regulatory setting in which that commitment is made. Section S4.3 in the Supplementary Material derives the criteria on that basis, assesses which of them the corpus can support as filters, and reports, for each criterion, how the studies satisfying it compare with those that do not.

Regulatory treatment is decisive, with levies charged on both withdrawal and reinjection able to turn a profitable schedule into a loss [75], as the German BDL pilot illustrates [144]. Most studies that include regulatory costs apply a single flat surcharge, not the asymmetric, country-specific rules real markets impose. Furthermore, the charging infrastructure is omitted in most articles. The median assumed cost of

780 EUR per vehicle is below a third of current bidirectional charger prices [133], and it is an up-front hurdle rather than a marginal cost. Availability is usually inferred from parking time, although empirical plug-in rates are far lower [124], and studies that use measured mobility data report a lower median and, more tellingly, agree with one another far more closely (Section 5).

A small set of real-world pilots offers limited contextual evidence against which the modeled economics can be placed; it does not validate them (Supplementary Material, Section S5). Most pilots have demonstrated technical feasibility rather than economic performance, and *no project reports a realized owner-level net result*. Only two report a per-vehicle market revenue measured in the field, and both figures are fragile, earned under temporarily relaxed terms or annualized from a single strong month: the Danish Parker project at roughly 1860 EUR per vehicle per year gross from frequency regulation [145], and the German BDL project at about 172 EUR gross from intraday trading [144]. Where a pilot reports a net value it is modeled rather than realized: Parker's modeled net profit of about 468 EUR is of the same order as our study-level median. The pilot record therefore confirms technical viability while leaving owner-level profitability unproven.

Restricting the corpus to studies that meet these requirements does not, however, lower the reported values. The eight studies that combine empirically grounded mobility with both battery degradation and charging infrastructure costs span a 21 EUR loss to a 2536 EUR profit per vehicle-year, and the five that additionally report a range rather than a single value span the same interval. Requiring one criterion separately point in both directions, so no subset supports a sharper estimate than the corpus. Even fully realistic modeling, however, would probably not fully close the gap to deployment, because EV flexibility is categorically different from the assets electricity markets were designed for (see Section 6.2).

6.2. Distinct characteristics of EV flexibility

Electricity markets were built for resources that are large, stationary, controllable, metered, and able to commit capacity ahead of delivery. EVs differ on every count, so even correctly modeled value is hard to turn into money the owner receives. Five properties, each visible in our corpus, show where that gap opens.

Size. A single EV is far too small for wholesale and balancing markets, where minimum bids start near 100 kW [104], so vehicles must be pooled by an aggregator. Whether market value reaches the owner depends on revenue-sharing and wear compensation mechanisms, a layer that most studies omit (Section 3.2) [13]. The literature therefore largely describes the value V2G creates rather than the share an owner ultimately keeps.

Availability. Plugging-in decisions are made by the vehicle owner and are driven by mobility needs rather than market signals. However, most products require guaranteed availability across long time windows (Section 4.2). Revenue models built on constant availability therefore overstate what can be delivered where participation depends on user behavior.

Cycling cost. Energy-trading strategies need frequent charging and discharging, with wear and losses on every cycle, while capacity strategies, paid for being available, avoid most of it. Deductions reach 90% of revenue under arbitrage but only 58% under balancing (Section 5), mostly because arbitrage must buy the energy it later sells; wear adds to this wherever owners and studies treat battery degradation as a real cost [146].

Locality. Markets clear regionally, but every cycle passes through the local distribution grid, which may not host many vehicles at once. This means that higher charging power does not simply raise profit, a limit most studies do not model.

Commitment timing. Owners prefer to commit late to preserve flexibility in case a trip arises, while operators require firm commitments early. However, most models assume perfect foresight of plug-in times (Section 4.5).

These properties are inherent to EV flexibility rather than modeling artifacts. EVs combine a structural cost advantage – a battery already paid for – with a structural uncertainty: availability depends on the user. V2G is therefore not a smaller stationary battery and should not be modeled as such.

6.3. Challenges in market segments and fleet-scale absorption

Most studies examine balancing markets, where vehicles are paid for availability rather than throughput, which limits cycling and suits EVs. Yet these markets are among the smallest: Germany's frequency containment reserve, its main balancing product, was about 1400 MW in 2024 [147], while the connectable EV fleet already exceeds this by an order of magnitude [148]. V2G does not enter an empty market but competes with stationary batteries – built on the same battery technology – for the same limited pool of reserve revenue, which is already eroding as storage scales, as observed in Nordic frequency regulation markets [149]. Vehicles themselves contribute little of this pressure today, since prequalification, metering, and product rules still exclude most of the fleet. However, these are the barriers that broad-participation studies abstract from. If standardized access is introduced, the sheer size of the fleet implies that even moderate participation would drive down reserve prices well before the entire fleet is active.

Wholesale markets pose a different challenge. Day-ahead and intraday auctions handle large volumes, but revenue depends on charging when prices are low and discharging when they are high, with wear and losses incurred in every cycle. Most studies treat prices as fixed inputs, yet this assumption breaks down at fleet scale: additional balancing supply compresses reserve prices, and the wholesale spreads exploited by V2G narrow. Current estimates therefore reflect conditions before this competitive feedback takes effect. Regulation can improve access and remove avoidable costs, but it cannot create additional reserve capacity or eliminate the cycling costs of arbitrage.

China illustrates a different form of geographical imbalance. It is the world's largest EV market and hosts a growing number of V2G pilots [55,150–152], yet contributes only two studies to our corpus, both from China-based groups that model foreign markets rather than the Chinese market itself. We interpret this under-representation cautiously. Part of it is methodological: the search and inclusion criteria covered English and German publications, so Chinese-language studies may be missed. Part of it is structural: China's power-sector liberalization began later than in Europe and North America, with market-oriented reforms introduced in 2015 and spot and ancillary-service markets emerging only in recent years [57,58]. Because our review focuses on market-based per-vehicle V2G revenue, domestic Chinese studies could only recently meet the market conditions central to our inclusion criteria.

6.4. Implications

Several technical conditions are improving, which shifts the binding constraint from technology to market and regulatory design. Battery prices have fallen to about 96 EUR/kWh [5], measured degradation is an order of magnitude below typical model assumptions [127,128], plug-in rates rise from around 25% to over 60% under structured incentives [124], and regulators are beginning to treat bidirectional storage as its own category [139]. The remaining task is not better batteries but better rules, products, and contracts.

For modelers, the dispersion we document is in part an artifact of what studies leave unreported, so the field needs a common reporting standard. Future profitability studies should report: the outcome as profit and revenue per EV per year, with currency, price base year, and

the range across scenarios; the cost scope, naming which components are included and excluded (degradation, bidirectional hardware and installation, metering, taxes, levies, network charges); the mobility basis, distinguishing idealized schedules from survey or telematics data, with the plug-in assumption; the market-integration model and whether access constraints (minimum bid size, prequalification, bid acceptance, activation) are modeled or assumed; the price basis, including segment, country, year, and whether prices are exogenous or include feedback at scale; the scheduling basis, stating the information horizon assumed and which inputs are treated as uncertain; and the underlying data, shared openly. Adopted consistently, these few items would let estimates be compared directly and shrink the heterogeneity this review had to reconstruct. Furthermore, model intercomparison projects could be valuable in the vehicle-to-grid field, as has been successfully demonstrated in energy system analysis and integrated assessment modeling [153], to systematically examine how differences in assumptions and model implementations affect estimated profitability.

For market designers and regulators, two questions separate: how vehicles reach a market, and how their flexibility is steered once in it. Access is largely common across segments. A single vehicle is too small to bid alone, so aggregation must be permitted; and because a vehicle both draws and returns electricity, levies and network charges can be applied twice, so bidirectional storage must be recognized as its own category rather than taxed as if consumed twice. Retail tariffs are a third route that avoids the size barrier, with the vehicle following a price signal rather than bidding, but they remain exposed to this double-charging. How flexibility is steered then differs by segment. In balancing markets the operator pays for availability and calls on the vehicle only when needed, which suits EVs and which our review finds owners favor; mechanisms like Denmark's P90 product, which lets a provider offer the capacity it can deliver at least 90% of the time, accommodate availability that is probable rather than certain [154]. In spot markets each participant traditionally sets its own schedule, yet a large fleet reacting to one price signal is hard to anticipate as participation grows. Products such as Nordic FlexiOrders and the storage orders under consultation for day-ahead coupling move the dispatch decision from the vehicle to the central market algorithm [155,156]: the vehicle states what it can do and a central instance plans the operation, keeping it flexible while the operator retains the predictability to hold the system stable. This shift from self-dispatch to central dispatch is underway in Europe and long established in U.S. pool markets, where V2G is nonetheless smaller given lower EV penetration.

For aggregators, the task is to win reliable plug-in commitments without giving away the value the fleet creates: pay owners for availability rather than throughput, and share value so participation is sustained, not concentrated in the aggregator [157].

Together these decide whether the EV fleet becomes a scalable flexibility resource or whether power systems must instead build dedicated storage, demand response, and grid reinforcement. The next frontier is not optimizing vehicle dispatch in isolation, but designing products that connect power-system needs with owner-level incentives.

6.5. Limitations

Several limitations apply. The across-study analysis is observational, with studies varying along multiple dimensions simultaneously and reporting parameters inconsistently. As a result, regressions cannot isolate individual characteristics. We therefore rely on within-study coherence – available only for the subset of studies that vary parameters across scenarios – as the primary test. The review is also model-based, reflecting modeled rather than realized field profitability. The classification framework cannot capture all variation within a category, such as the optimization formulations grouped under scheduling.

Summarizing each study by a single value also discards the spread within studies, which is itself informative: in 16 of the 49 studies

reporting several scenarios, the reported values fall on both sides of zero.

Studies also contribute unequally, so subgroup statistics are sensitive to composition. Profit definitions differ in which costs they include, and because components are not always reported separately, we cannot fully normalize them; heterogeneity therefore persists within our own categories. Differences between groups of studies should therefore not be read as effects of the coded dimension alone. A further limitation is inherited from the source studies, which do not consistently state whether a reported value is the aggregator's account or the owner's (Section 3.2). Where studies leave it implicit we assign the perspective from the price entering the economic calculation rather than from the authors' terminology, a rule applied by a single coder; four studies were reassigned on re-examination against their full texts, and we cannot report an independent agreement statistic. Absolute levels and subgroup medians are thus perspective-mixed, while our dispersion finding and the perspective-fixed within-study comparisons are not. The review covers bidirectional V2G only, not V1G or other EV flexibility, and excludes distribution-network effects and second-life battery value. The search covered English and German, which may under-represent other languages, Chinese in particular. This language filter matters especially for China, where rapid EV deployment and V2G pilots coexist with a later transition toward market-based electricity trading; China-specific results should therefore be read as evidence from the included English- and German-language market-based literature, not as a measure of Chinese V2G activity overall. Finally, selective publications may inflate the share of positive results, so that share should be read with care; it would not, however, create the order-of-magnitude spread or the within-versus-across-study contrast that is our central finding, and a funnel test is not meaningful where studies share no common effect.

7. Conclusion

The reviewed literature shows that vehicle-to-grid can create economic value, but it does not pinpoint a profit level that can be generalized across markets, jurisdictions, or participation models. Harmonizing 680 outcomes from 86 studies reveals why: reported values come from highly diverse study designs that combine different market segments, price environments, availability assumptions, cost components, activation treatments, and scheduling methods. Within individual studies, where much of the modeling context is shared, profitability follows coherent economic logic: it rises with deployable flexibility and falls with cycling-related costs, and this holds whether a study varies one parameter or several. Across studies, this signal is no longer detectable. Market environments, regulatory treatments, cost definitions and modeling choices vary together, and with the available evidence their contributions cannot be separated: within studies, all ten examined parameters show a directional majority in the direction economic reasoning predicts, whereas the corresponding cross-study correlations are near zero or carry the opposite sign. This is not merely an artifact of study design: market heterogeneity is itself part of vehicle-to-grid economics. Reported profits, therefore, describe conditional values under specific modeling setups, not a general estimate of deployable vehicle-to-grid profitability. This result shifts the profitability question from whether vehicle-to-grid can create value in models to whether modeled value can be realized in practice. The decisive issue is under which market products, user contracts, and regulatory rules vehicle-to-grid becomes valuable for the power system and worthwhile for vehicle owners.

On the revenue side, the key uncertainty is not whether electric vehicles can technically shift energy or provide capacity, but whether this flexibility can be turned into dependable services for renewable-dominated power systems. The realism of these estimates is unevenly distributed: coverage declines from the vehicle outward to the market setting, and almost no study is complete across all three layers. Taking one requirement from each, only two of the 69 studies meet all of them,

while half meet exactly one. Reported profits should therefore generally be read as potential values rather than as returns that aggregators or vehicle owners can reliably capture. That framing describes what studies omit, not what they report: restricting the corpus toward greater completeness does not lower the reported values, and the studies that come closest are concentrated in the more lucrative market segments. Modeling realism is not a dimension along which this literature orders itself, and no subset of it can stand in for a more realistic estimate. Future market products need to translate the system value of electric vehicle flexibility into revenue streams that electric vehicles can actually deliver, including through pooled participation, probabilistic availability, shorter commitment horizons, and remuneration schemes that make plugging in and allowing dispatch worthwhile. The cost side points in a different direction. Falling battery prices and empirically observed lower degradation rates reduce the cost of cycling, weakening one of the main objections to bidirectional use. The corpus itself shows how far its own assumptions lag: studies cost battery aging at a median assumed battery price of 334 EUR₂₀₂₅ per kWh, against cell prices of roughly 60 to 100 EUR per kWh in 2025, and their assumed degradation cost halves between studies published before 2015 and after 2020. Completeness and accuracy are different requirements, and a study that internalizes a cost on outdated parameters is not thereby closer to the truth. Bidirectional charging hardware should also become cheaper as products mature and scale, although many studies still understate the full deployment cost by omitting installation, certified metering, communication, and backend integration. Taxes, levies, network charges, and metering rules remain decisive because they determine whether bidirectional storage retains value or loses it when electricity is withdrawn and later reinjected. Clear rules for bidirectional electricity flows can preserve the value created by flexible charging and discharging, and early regulatory frameworks are beginning to clarify how these flows should be treated.

If market products, user contracts, and regulatory rules are aligned, the global electric vehicle fleet can move from a largely passive load to a scalable flexibility resource for renewable integration. If markets and rules do not adapt, power systems will need more dedicated storage, demand response, or grid reinforcement to achieve the same level of flexibility. The next frontier for vehicle-to-grid research and policy is therefore not to optimize vehicle dispatch in isolation, but to design market products that connect power-system needs with owner-level incentives. These products must reward flexibility where it supports renewable integration, balancing, or grid constraint management, while giving vehicle owners a clear business case for making their vehicles available.

CRedit authorship contribution statement

Tim Signer: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Max Kleibrach:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Thorsten Weiskopf:** Writing – review & editing. **Jann M. Weinand:** Writing – review & editing. **Moritz Raab:** Writing – review & editing. **Vincenz Regener:** Writing – review & editing. **Wolf Fichtner:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at <https://doi.org/10.1016/j.adapen.2026.100306>.

Data availability

Data for this article, including a harmonized dataset of 680 scenarios from 86 studies with full technical parameters and financial outcomes, together with the analysis script that regenerates every reported quantity, are available at Zenodo at <https://doi.org/10.5281/zenodo.22043327>. The data supporting the statistical appendix have been included as part of the Supplementary Material, submitted alongside this manuscript.

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